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AN EXPERIMENTAL AERIAL SURVEY FOR VAQUITA (*PHOCOENA SINUS*) IN THE NORTHERN GULF OF CALIFORNIA, MEXICO

The vaquita (*Phocoena sinus*) is endemic to the Gulf of California and all recent sightings have been in the northern Gulf (Silber 1990*a, b*) where most survey efforts for this species have been concentrated. Previous ship surveys for this species were conducted by Villa-R. (1976), Wells *et al.* (1981), Vidal *et al.* (1987), and Silber (1990*b*) (Table 1). Aerial surveys were also conducted by Silber (1990*b*) and Silber and Norris (1991). None of these surveys produced quantitative estimates of vaquita population size. We conducted an experimental aerial survey in the northern Gulf of California from 11 to 14 September 1991 to evaluate the feasibility of using aerial census methods to estimate vaquita population size.

The line-transect methods and aircraft used in this experimental work were the same as were used in quantitative surveys of harbor porpoise (*Phocoena phocoena*) in California (Forney *et al.* 1991). The aircraft was a twin-engine Partenavia P-68 fitted with bubble windows on each side and a 20 × 30-cm viewing port in the belly of the aircraft. Direct downward visibility was possible from all three observer positions. Surveys were flown at an airspeed of 166 km/h and an altitude of 183 m. Transects were established on a uniform grid at 22.2 km spacing (Fig. 1). The starting point of the grid was chosen arbitrarily as the intersection of latitude 30°45′N with the eastern shoreline of the Gulf. The initial survey design included only areas north of 30°45′N (which enclosed the area of all confirmed sightings reported by Silber [1990*b*]). Survey lines were added in shallow waters immediately south of the primary grid along the western shoreline of the Gulf after hearing a report by local fishermen of vaquita

Table 1. Scientifically documented sighting history for vaquitas in the Gulf of California. Effort indicates the number of transect km surveyed (by boat unless noted otherwise). Caveats on identification expressed by the author are given below the source citation.

Date	Effort	Number sightings	Number individuals	Approximate location	Source
Jan 1951	—	1	2	Topolobampa	Norris and McFarland (1958) (identification doubtful)
Feb 1953	—	1	1	San Carlos	Norris and McFarland (1958) (identification doubtful)
Apr 1955	—	1	3	San Felipe	Norris and McFarland (1958)
Feb 1956	—	1	"large group"	Conception Bay	Norris and McFarland (1958)
May 1956	—	1	1	Bacochibampo Bay	Norris and McFarland (1958) (identification probable)
Apr–May 1976	720 km	3	5	San Francisquito Bay	Villa-R. (1976)
Mar 1981	1,959 km	2	5	Puerto Peñasco	Wells *et al.* (1981)
Spring 1984	1,665 km	1	1	—	Vidal *et al.* (1987)
1985–1986	—	20	—	—	Pérez-D. (1987)
1986	300 km	1	1	Santa Clara	Turk *et al.* (1986)
Feb–Mar 1986	815 km	12	27	San Felipe	Silber (1987)
Apr–May 1987	300 km	22	46	San Felipe	Silber (1987)
Mar–May 1988	130 km	8	12	San Felipe	Silber (1990*a*)
May 1988	1,521 km aircraft	5	11	San Felipe	Silber (1990*a*)
Sep 1989	980 km aircraft	7	14	San Felipe	Silber and Norris (1991)
Sep 1991	1,143 km aircraft	1	2	Puertecitos	this paper

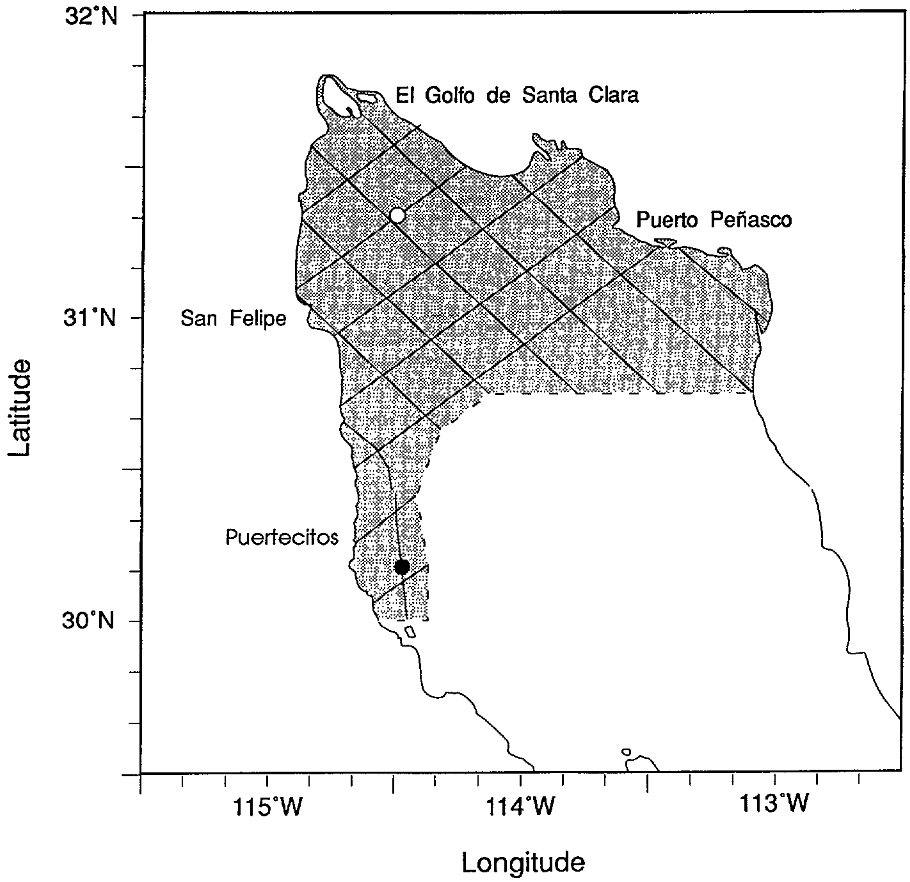

Figure 1. Survey transect lines flown in the northern Gulf of California during the experimental aerial survey for vaquitas. The lower (southernmost) solid circle indicates the position of the only confirmed sighting of vaquitas. The upper open circle indicates the position of a probable sighting.

being in that area in September. All transects were flown towards the northwest in the mornings and towards the northeast in the afternoons to minimize sun glare. Observers consisted of the four authors, who rotated among four positions. Two of the observers (J.B. and K.A.F.) have extensive experience (>3 yr) conducting similar aerial surveys for *Phocoena phocoena.* The primary observer team consisted of left (seated behind pilot), right (seated behind recorder), and belly (lying down in rear of aircraft and viewing through the belly port) positions. The fourth position was data recorder (in the co-pilot seat). The pilot and data recorder were instructed not to mention cetacean sightings until after they had passed out of the field of view of the primary observation team. The perpendicular distance from the transect line to any observed marine mammal was calculated from altitude and declination angle measured using hand-held clinometers. The width of the search path was unbounded, but observers were told to concentrate their efforts close to the trackline. Information on changes in sea state and viewing conditions were recorded immediately on a lap-top computer which was linked to aerial navigation instruments. Position was determined by LORAN which had been calibrated using a GPS satellite navigation device.

A total of 1,143 km was completed on aerial transect lines during 3.5 d of surveying. Two transect lines in the southeast (not shown in Fig. 1) were not completed due to insufficient time. All transects were completed under clear skies and with Beaufort sea state conditions of 0–1 (155 km), 2 (503 km), 3 (472 km), or 4 (13 km). Only one sighting of two vaquita was made by the primary survey team. Another probable sighting of one vaquita was made by the data recorder. [Sightings made by the data recorder are typically not used in harbor porpoise population estimates because the fraction of time they are actively searching is difficult to quantify (Barlow *et al.* 1988).] Other species seen included common dolphins (*Delphinus delphis*), bottlenose dolphins (*Tursiops truncatus*), false killer whales (*Pseudorca crassidens*), fin whales (*Balaenoptera physalus*), minke whales (*Balaenoptera acutorostrata*), and California sea lions (*Zalophus californianus*).

The only certain vaquita sighting was made south of San Felipe, Baja California Norte, under clear skies, with Beaufort 1, and in relatively clear waters (Fig. 1). Two vaquitas were traveling rapidly approximately 2 m under the surface, breathing relatively infrequently in the characteristic "pop-splash" of rapidly moving harbor porpoise (Taylor and Dawson 1984). All observers obtained a good view of these animals while the aircraft circled. The other, "probable" sighting occurred in the region north of Rocas Consag where vaquitas have been most frequently reported (Silber 1990*b*) (Fig. 1). That sighting occurred in very turbid waters by only one person for less than 1 sec. The animal surfaced once and dived straight down, disappearing within 1 m of the surface due to the turbid conditions. Based on extensive experience on harbor porpoise aerial surveys, the data recorder (K.A.F.) classified that animal as a probable *Phocoena*.

Clearly, insufficient sightings were made to make a reliable line-transect estimate of vaquita population size from this survey. However, it is clear that vaquita were relatively scarce in our study area. Both *Tursiops* and *Delphinus* were seen more frequently. The sighting rate for vaquitas was 1.8 per 1,000 linear km surveyed (or 2.6 per 1,000 km including the "probable" sighting). This is lower than sighting rates on previous aerial surveys which concentrated effort in areas of presumed high density: 7.2 vaquitas per 1,000 km (Silber 1990*b*) and 7.0 per 1,000 km (Silber and Norris 1991). In contrast, 47.0 harbor porpoise per 1,000 km were seen on systematic aerial surveys in central California (Forney *et al.* 1991).

Although this study and others (Silber 1990*b*, Silber and Norris 1991) have shown that vaquitas can be seen from aircraft, quantitative aerial surveys for this species are plagued by difficulties and uncertainties. From the sighting rate of this survey, it is clear that a much larger-scale survey is needed for reliable population estimates. A sample size of 100 sightings is desirable to allow stratification by Beaufort sea state and cloud cover, factors that have been shown to be important in harbor porpoise aerial surveys (Forney *et al.* 1991). This would require a great amount of effort, and a synoptic survey of this magnitude would require the coordinated work of several aircraft. Another major impediment is the difficulty in quantifying the fraction of animals that are visible from the air. A simple line transect estimate only represents the number visible from the air at any given moment. For harbor porpoise seen in relatively clear waters in California, a correction factor of 3.2 has been used to account for submerged animals that would not be visible from the air (Barlow *et al.* 1988). A correction factor for submerged animals is likely to depend on water turbidity. Turbidity in the northern Gulf of California is typically much greater than in California and is influenced by tides and by sediment transport from the Colorado River. Turbidity in the Gulf changes markedly over very short distances. Not only would several correction factors be needed for different water turbidities, but also some method would be needed to accurately quantify turbidity during aerial surveys. Uncertainty in estimating these (probably large) correction factors would add considerable uncertainty to quantitative estimates of population size. Future aerial surveys should be preceded by studies of the fraction of time vaquitas are visible from the air, perhaps using the type of helicopter experiment that was used to obtain these data for harbor porpoise (Barlow *et al.* 1988).

Turbidity and fraction of time spent at the surface are less of a problem for ship than for aerial surveys. Although cetaceans are typically seen from ships only when some part of the animal is above the surface, surface vessels travel relatively slowly and most animals will surface at least once within the visual range of the ship. Given the difficulty and uncertainty in estimating the large correction factors for submerged animals on aerial surveys, effort might be better allocated to large-scale ship surveys.

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